US009638478B2

(12) **United States Patent**
Byman

(10) **Patent No.: US 9,638,478 B2**
(45) **Date of Patent: May 2, 2017**

(54) **HEAT EXCHANGER FOR COOLING BULK SOLIDS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 377 days.

(21) Appl. No.: **14/341,440**

(22) Filed: **Jul. 25, 2014**

(65) **Prior Publication Data**

US 2016/0025417 A1 Jan. 28, 2016

(51) **Int. Cl.**

F28F 3/14	(2006.01)
F28F 9/02	(2006.01)
F28D 7/08	(2006.01)
F28D 21/00	(2006.01)

(52) **U.S. Cl.**

CPC ***F28F 3/14*** (2013.01); ***F28D 7/082*** (2013.01); ***F28F 9/0246*** (2013.01); *F28D 2021/0045* (2013.01); *F28F 2230/00* (2013.01)

(58) **Field of Classification Search**

CPC C10J 3/52; F26B 17/126; F26B 17/16; F28D 7/0066; F28D 7/087; F28D 7/1615; F28D 7/1623; F28D 9/00; F28D 9/006; F28D 9/0093; F28D 9/0031; F28D 2021/0045; F28D 7/082; F28F 1/045; F28F 3/14; F28F 9/0246; F28F 2230/00

See application file for complete search history.

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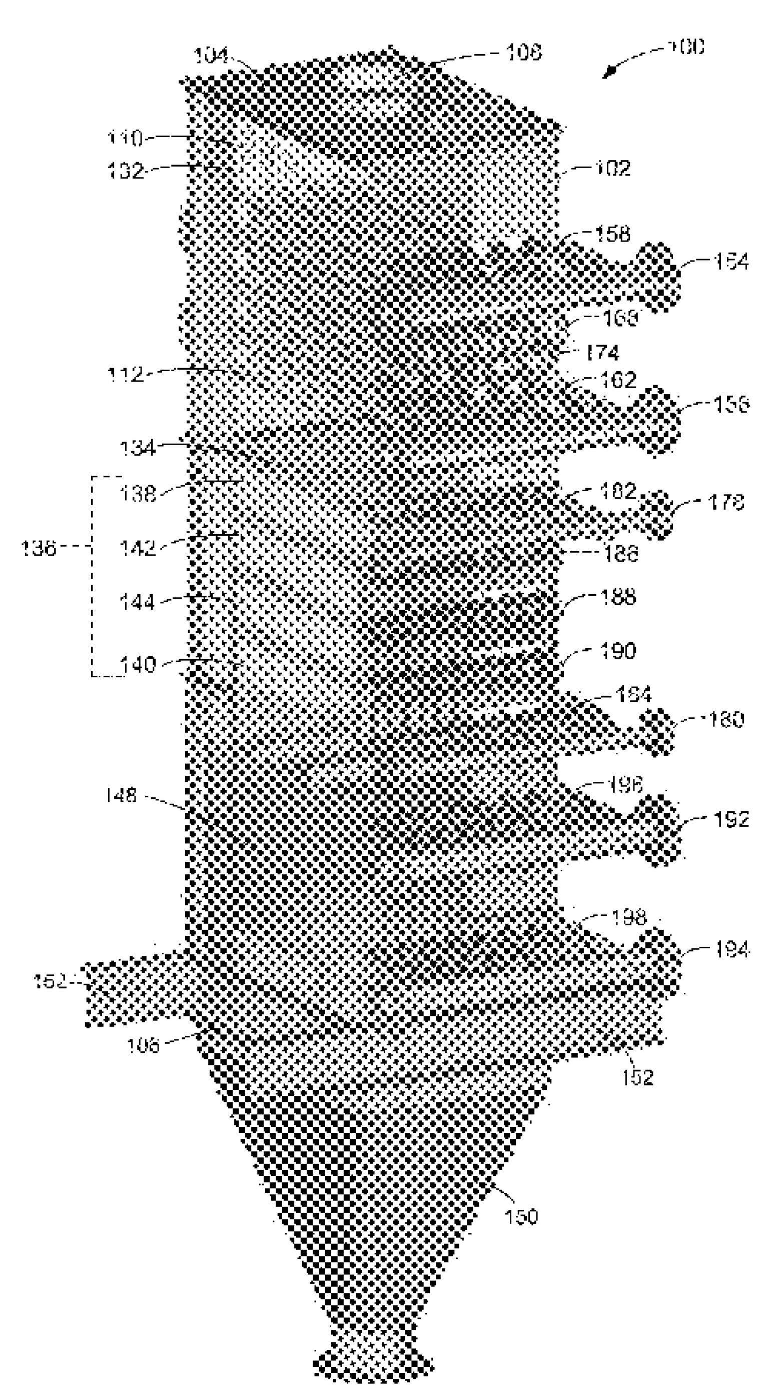
(57) **ABSTRACT**

A heat exchanger comprises a housing that includes an inlet for receiving bulk solids having a first temperature, and an outlet for discharging the bulk solids. A plurality of spaced apart, substantially parallel heat transfer tubes are disposed within the housing between the inlet and the outlet, for cooling the bulk solids that flow from the inlet into spaces between heat transfer tubes, to a second intermediate temperature, and a plurality of spaced apart, substantially parallel heat transfer plate assemblies disposed within the housing and interposed between the plurality of heat transfer tubes and the outlet for further cooling the bulk solids that flow from the spaces between heat transfer tubes, to spaces between heat transfer plate assemblies and to the outlet, to a third temperature.

18 Claims, 10 Drawing Sheets



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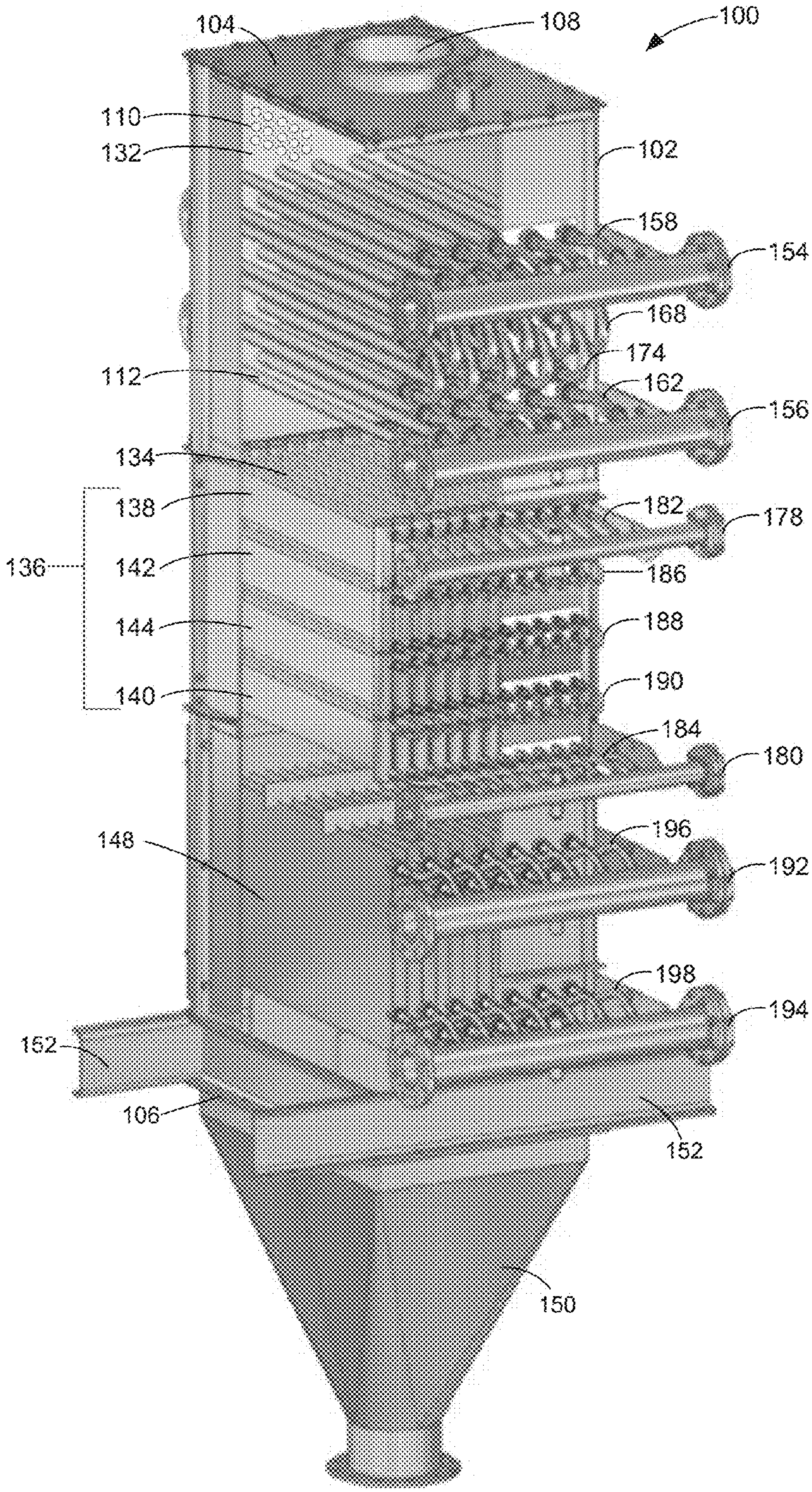

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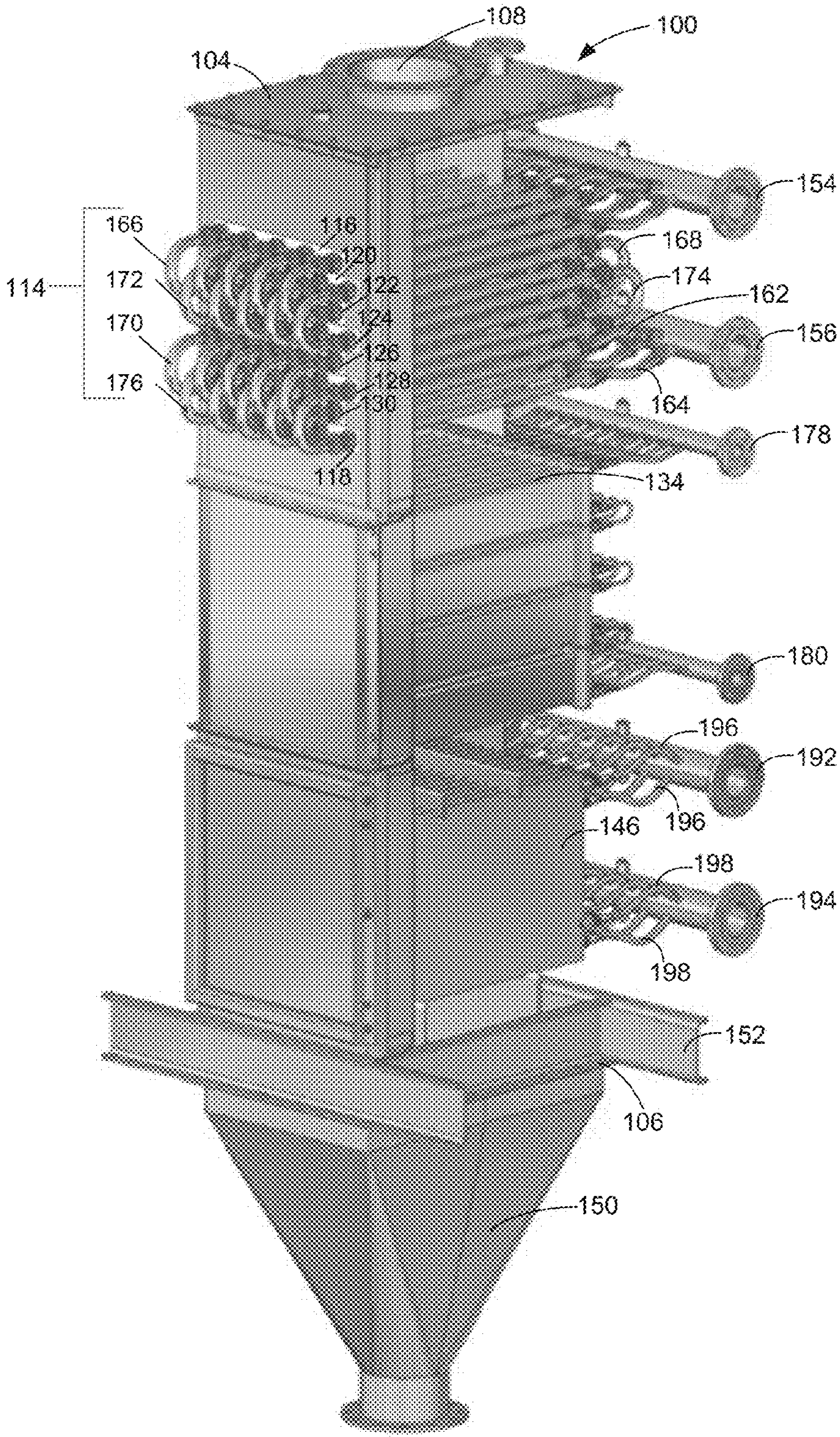
FIG. 1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100
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154
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114
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156
126
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178
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134
180
196
192
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146
198
194
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152
106
150

FIG. 2

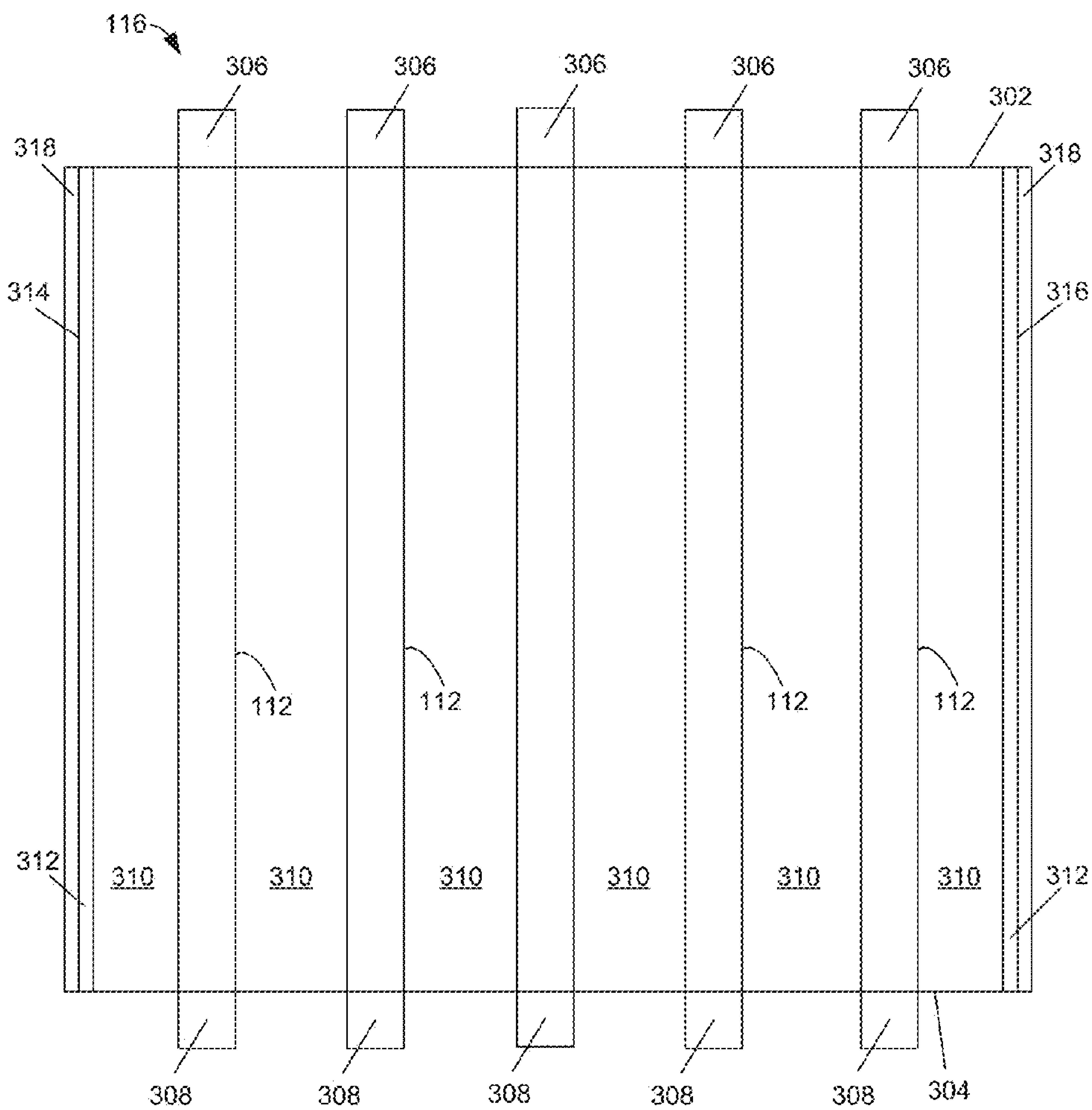
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FIG. 3

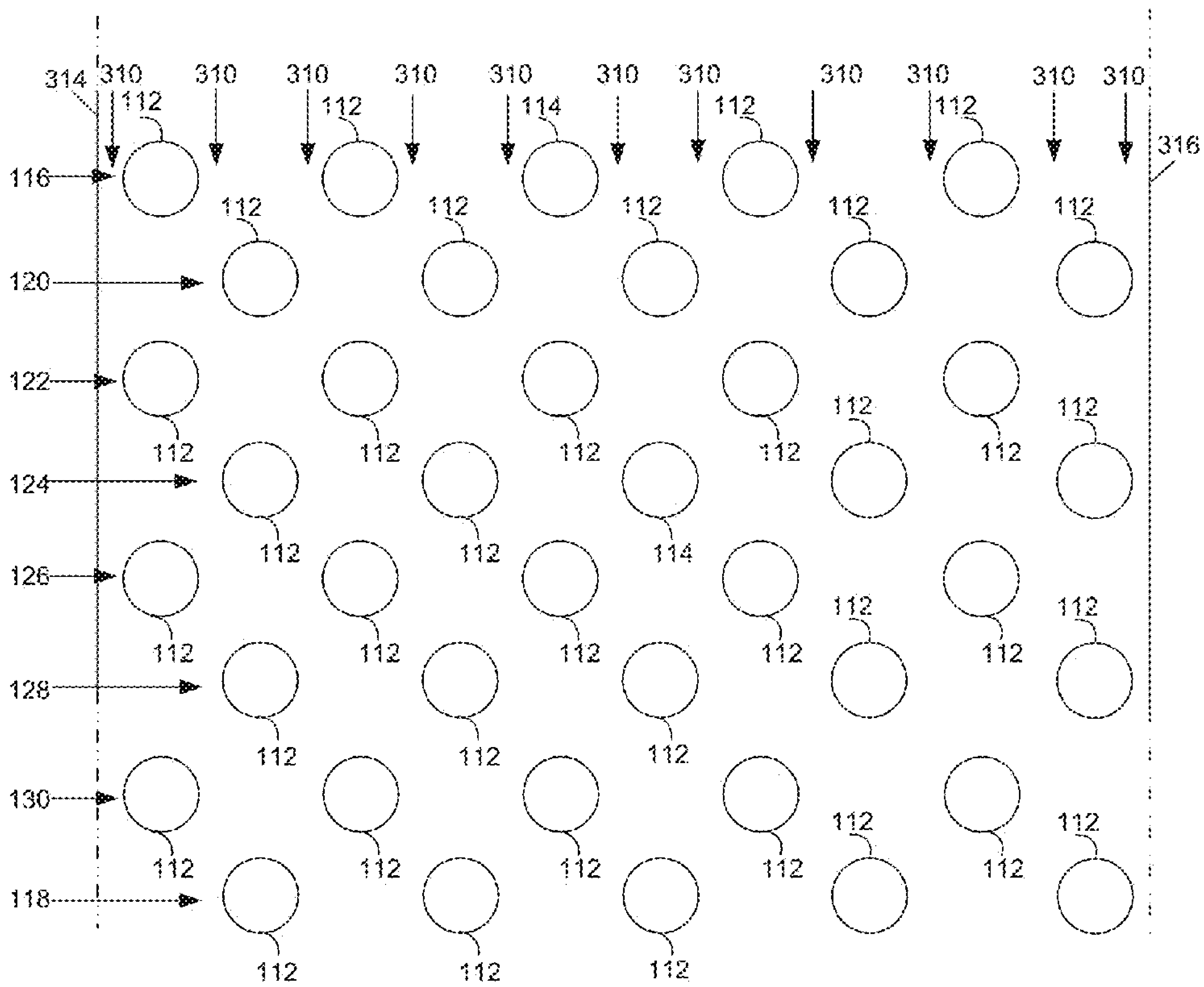
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FIG. 4

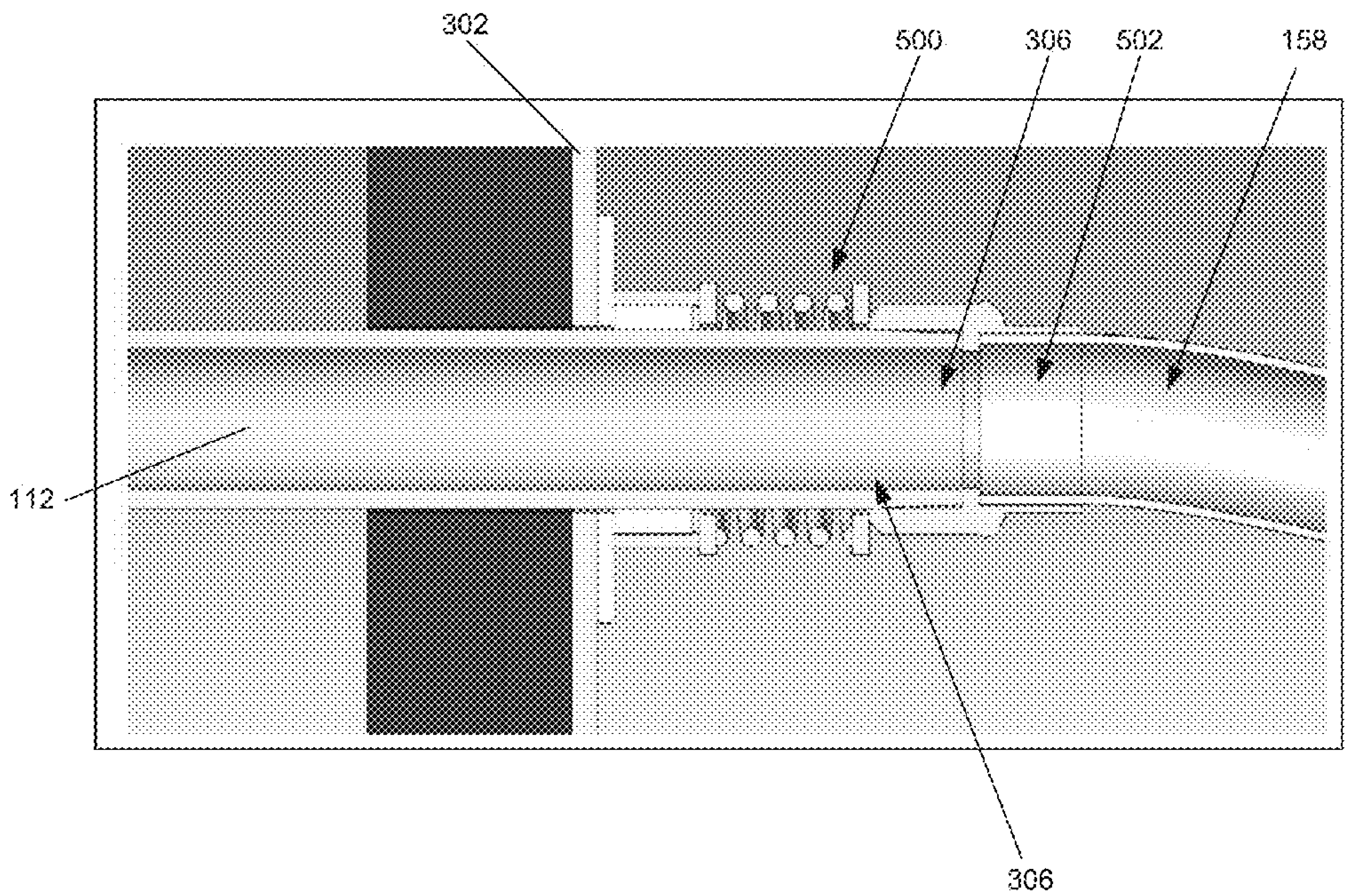

FIG. 5

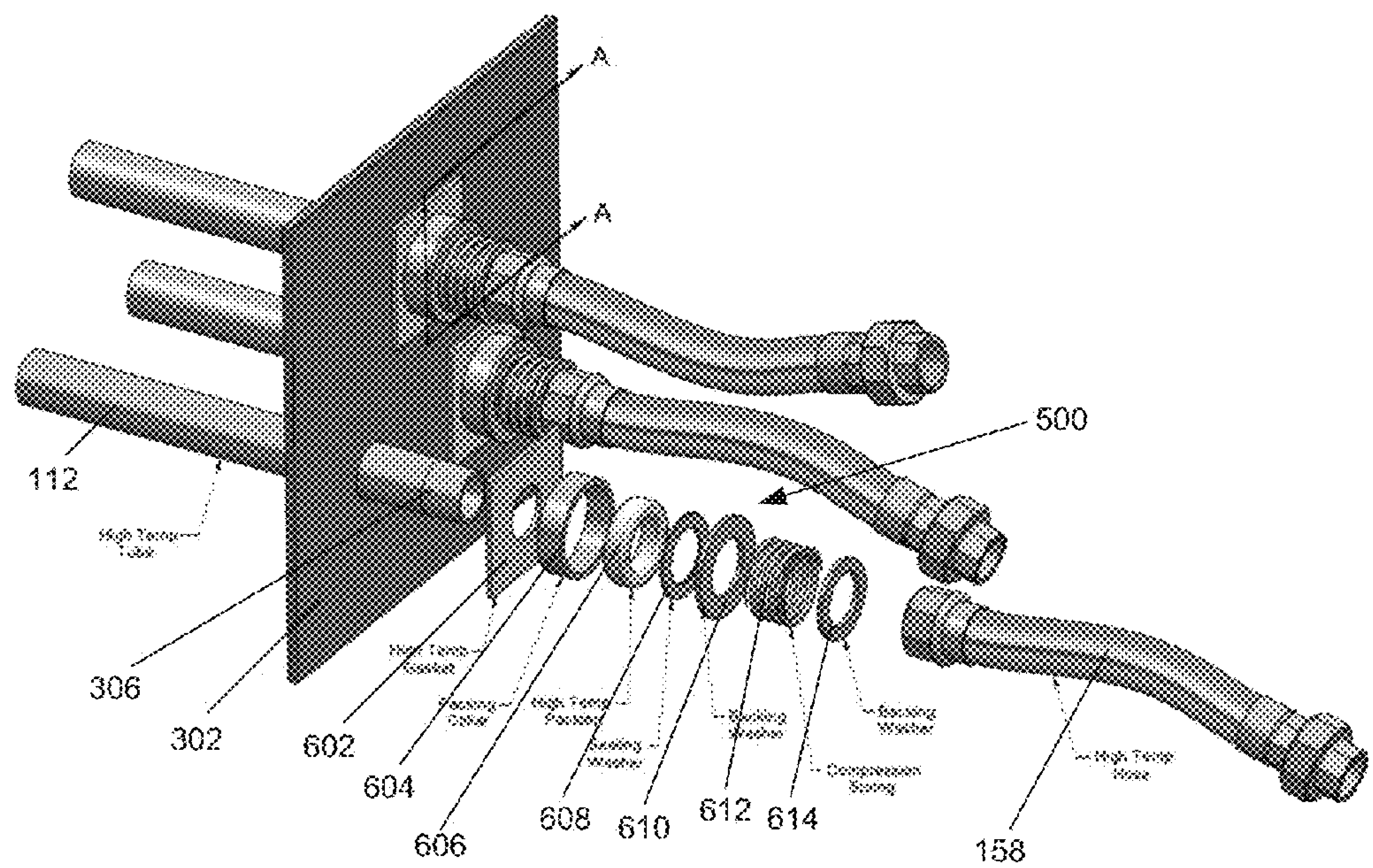
A
A
500
112
High Temp Tube
306
302
602
604
606
608
610
612
614
158
High Temp Hose

FIG. 6

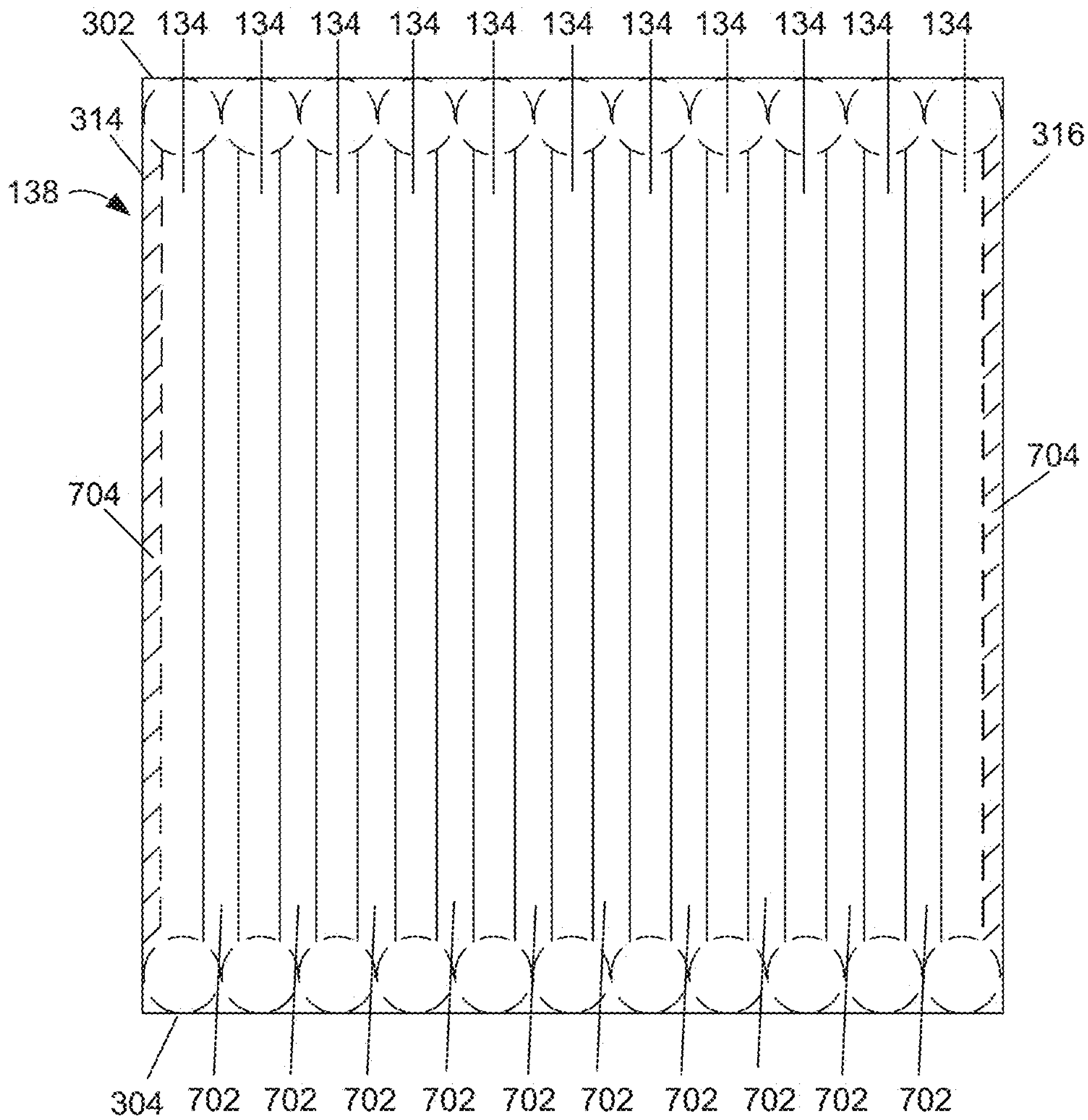
302
134
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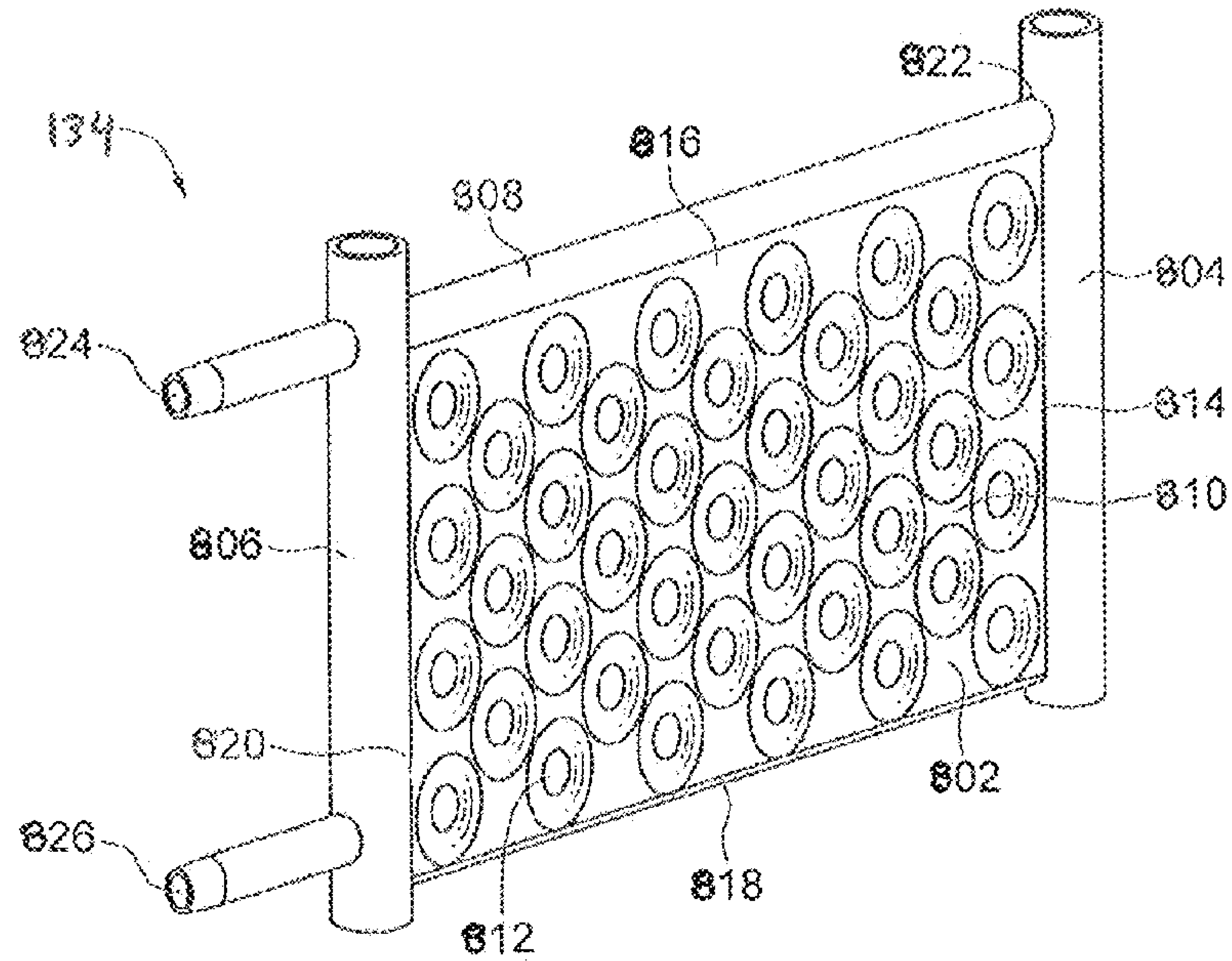
FIG. 7


134
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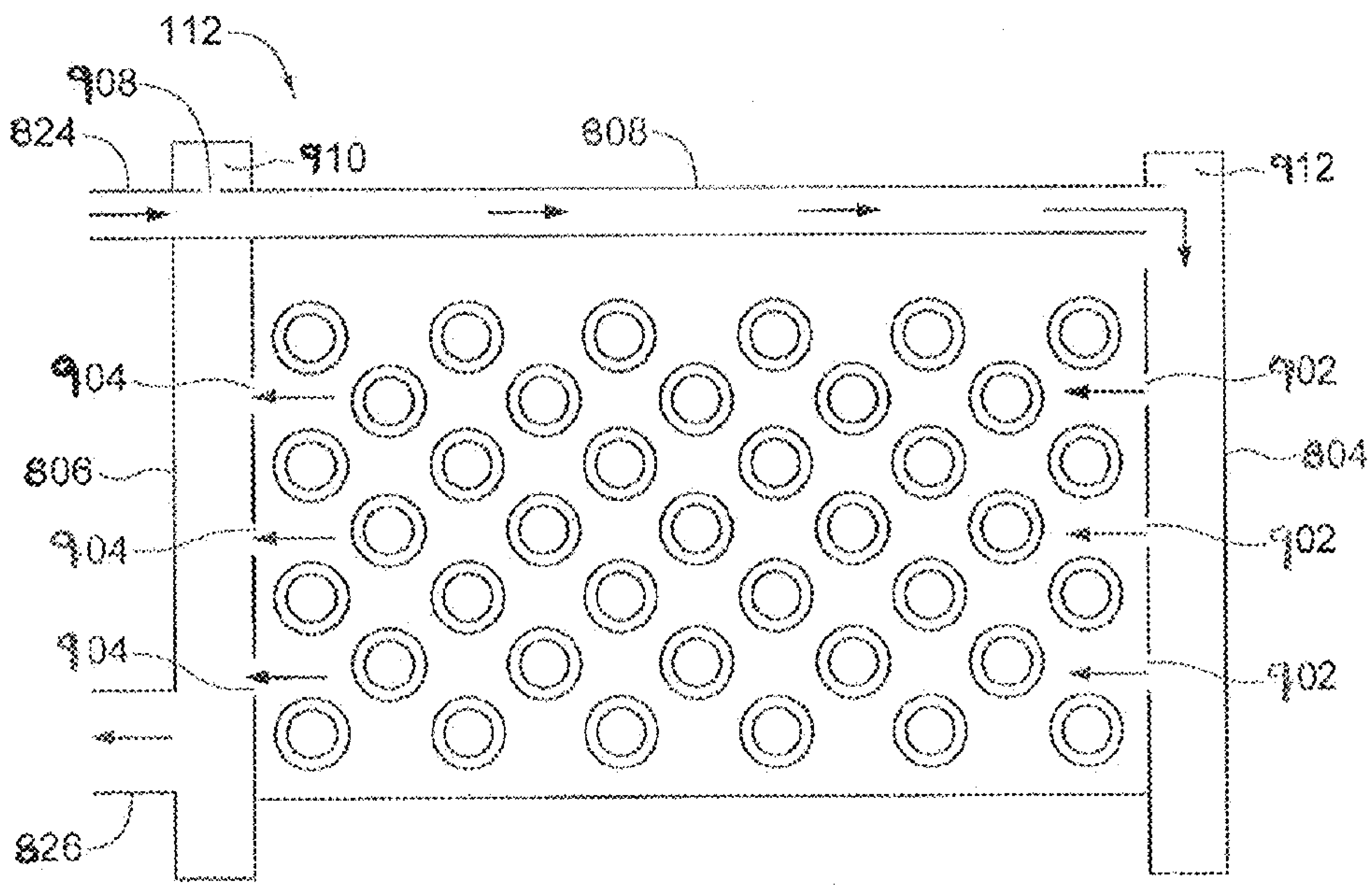
802
826
818
812

FIG. 8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804
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FIG. 9

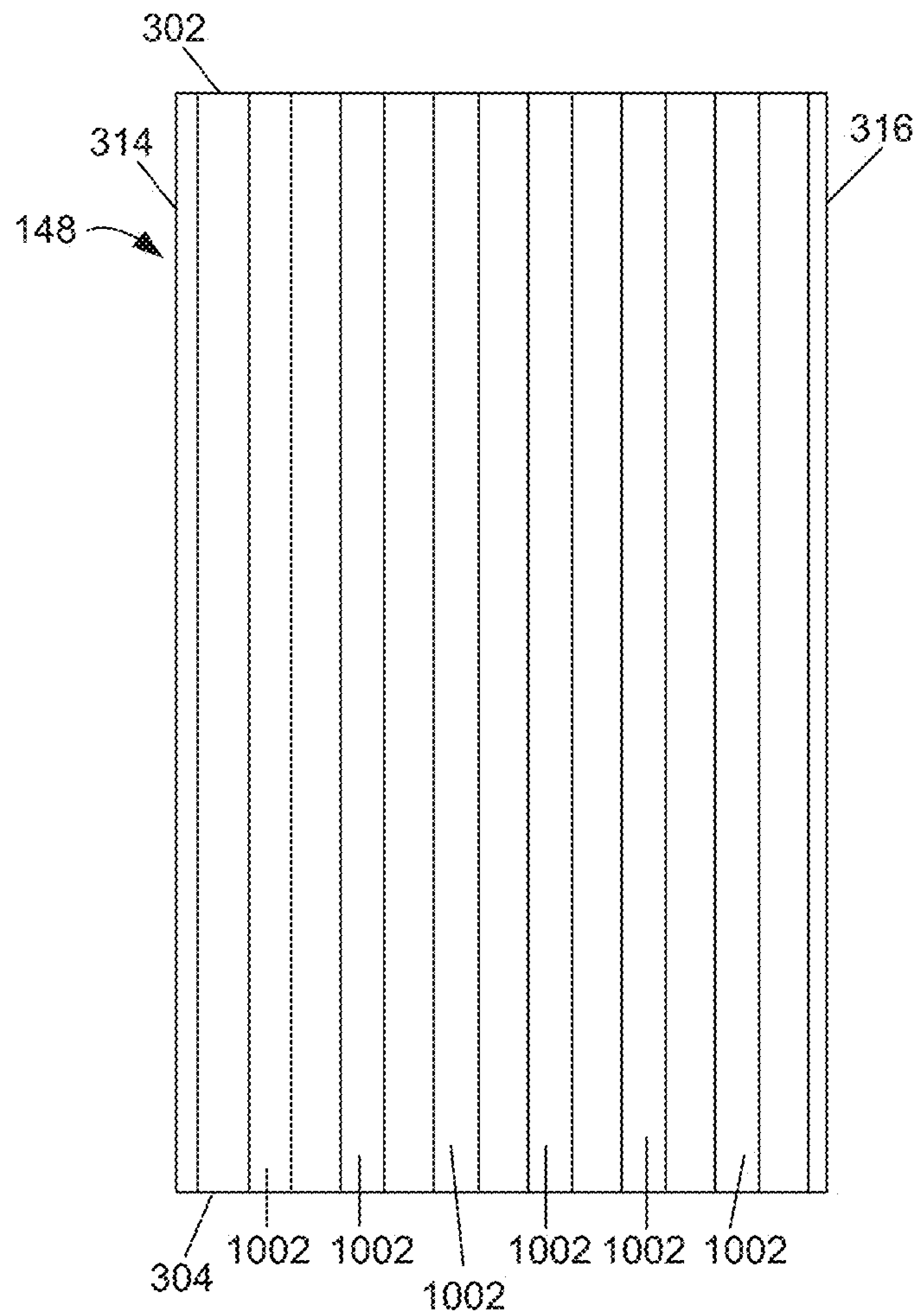

FIG. 10

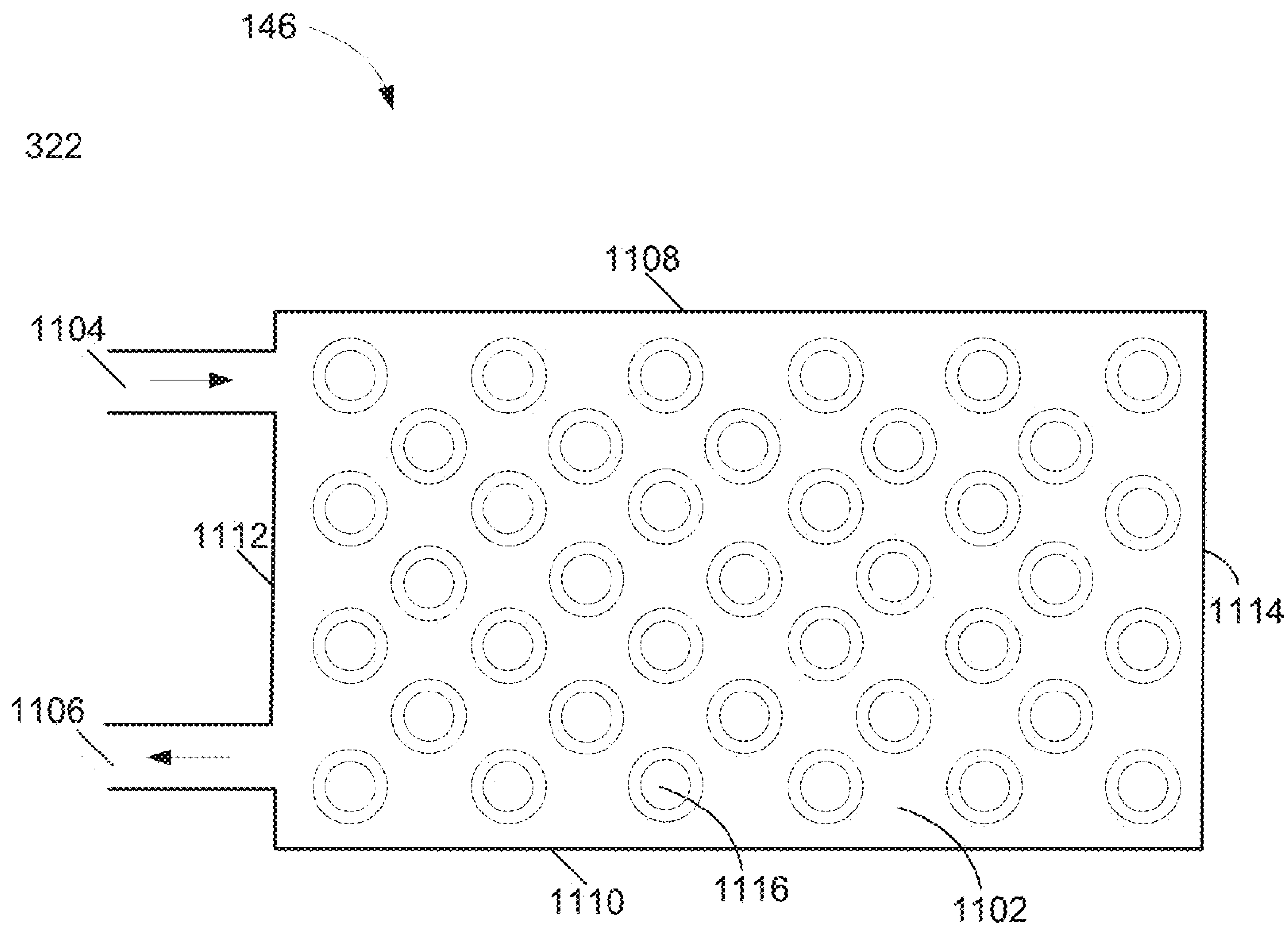

FIG. 11

HEAT EXCHANGER FOR COOLING BULK SOLIDS

FIELD OF THE INVENTION

The present disclosure relates to a heat exchanger for cooling bulk solids, for example, metal powders, ash, coke, coals, carbon powders, and graphite powders.

BACKGROUND

Heat exchangers are used to cool bulk solids that have a high temperature and that flow, under the force of gravity, through the heat exchanger. The operation life of known heat exchangers is limited because indirect cooling elements of the heat exchanger become worn as the bulk solids flow through the heat exchanger. Improvements to heat exchangers to extend their operational life are therefore desirable.

SUMMARY

According to one aspect of an embodiment, a heat exchanger includes a housing including an inlet for receiving bulk solids having a first temperature, and an outlet for discharging the bulk solids. A plurality of spaced apart, substantially parallel heat transfer tubes are disposed within the housing between the inlet and the outlet, for cooling the bulk solids that flow from the inlet, to spaces between heat transfer tubes, to the outlet, to a second intermediate temperature, and a plurality of spaced apart, substantially parallel heat transfer plate assemblies disposed within the housing and interposed between the plurality of heat transfer tubes and the outlet for further cooling the bulk solids that flow from the spaces between heat transfer tubes, to spaces between the heat transfer plate assemblies, and to the outlet, to a third temperature.

The first temperature may be between about 400° C. and about 2400° C., the second intermediate temperature may be less than the first temperature and greater than or equal to about 400° C., and the third temperature may be about 400° C. or less. The first ones of the plurality of heat transfer tubes may be arranged in a first row, and second ones of the plurality of heat transfer tubes may be arranged in a second row such that the heat transfer tubes of the second row are spaced from the heat transfer tubes of the first row. Each heat transfer tube of the second row may be disposed between adjacent heat transfer tubes of the first row. The third ones of the plurality of heat transfer tube assemblies may be arranged in a third row such that the heat transfer tube assemblies of the third row are spaced and aligned with respective heat transfer plate assemblies of the first row.

According to another aspect of an embodiment, the heat exchanger includes a refractory lining disposed within the housing between a first sidewall of the housing and the heat transfer tubes adjacent the first sidewall of the housing for cooling the bulk solids that flow between the first sidewall of the housing and the first heat transfer tubes located adjacent the first sidewall of the housing. The refractory lining may also be disposed within the housing between an opposing second sidewall of the housing and the heat transfer tube assemblies located adjacent the second sidewall of the housing to reduce the chance of overheating the housing.

According to another aspect of an embodiment, a first end of the heat transfer tube assemblies may pass through the first sidewall of the housing and a second end of the heat transfer tube assemblies pass through the second sidewall of the housing. The first end of the heat transfer tube assemblies of the first row may be coupled to the first sidewall of the housing by a first seal.

According to another aspect of an embodiment, the heat exchanger also includes a cooling fluid inlet manifold in fluid communication with each first seal for providing cooling fluid into each heat transfer tube assembly of the first row. The second end of each heat transfer tube assembly of the first row may be in fluid communication with the second end of each heat transfer tube assembly of the second row for providing cooling fluid into each heat transfer tube assembly of the second row. The first end of each heat transfer tube assembly of the second row may be coupled to the first sidewall of the housing by a second mechanical seal.

According to another aspect of an embodiment, the heat exchanger also includes a cooling fluid discharge manifold in fluid communication with each second seal for receiving cooling fluid discharged from each heat transfer tube assembly of the second row. The cooling fluid may be liquid. The liquid may be one of water and thermal oil. Alternatively, the cooling fluid may be a gas under pressure. Each of the plurality of heat transfer plate assemblies are low temperature heat transfer plate assemblies. Each of the plurality of heat transfer plate assemblies may be high temperature heat transfer plate assemblies.

According to another aspect of an embodiment, the heat exchanger also includes a plurality of spaced apart, substantially parallel low temperature heat transfer plate assemblies disposed within the housing and interposed between the plurality of high temperature heat transfer plate assemblies and the outlet for further cooling the bulk solids that flow from the spaces between high temperature heat transfer plate assemblies, to spaces between the low temperature heat transfer plate assemblies and to the outlet, to a fourth temperature. The first temperature may be about 2400° C., the second intermediate temperature may be less than the first temperature and greater than or equal to about 400° C., and the third temperature may be about 400° C. or less.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will be described, by way of example, with reference to the drawings and to the following description, in which:

FIG. **1** is a partially cut away front perspective view of a heat exchanger for cooling bulk solids in accordance with an embodiment;

FIG. **2** is a partially cut away rear perspective view of the heat exchanger of FIG. **1**;

FIG. **3** is a top view of a top bank of heat transfer tubes of the heat exchanger of FIG. **1**;

FIG. **4** is an end view of an example embodiment of a heat transfer tube stack of the heat exchanger of FIG. **1**;

FIG. **5** is a side view of a portion a heat transfer tube of a top heat transfer tube bank of the heat exchanger of FIG. **1**, that illustrates an example of a seal between an end of a heat transfer tube and an end of a fluid line;

FIG. **6** is an exploded perspective view of an example embodiment of a seal of the heat exchanger of FIG. **1**;

FIG. **7** is a top view of a top bank of heat transfer plate assemblies of the heat exchanger of FIG. **1**;

FIG. **8** is a perspective view of an example of a heat transfer plate assembly of the heat exchanger of FIG. **1**;

FIG. **9** is a sectional view of the high temperature heat transfer plate assembly of FIG. **8**;

FIG. **10** is a top view of a bank of heat transfer plate assemblies of the heat exchanger of FIG. **1**; and

FIG. **11** is a sectional view of an example of a heat transfer plate assembly of the heat exchanger of FIG. **1**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

For simplicity and clarity of illustration, reference numerals may be repeated among the figures to indicate corresponding or analogous elements. Numerous details are set forth to provide an understanding of the embodiments described herein. The embodiments may be practiced without these details. In other instances, well-known methods, procedures, and components have not been described in detail to avoid obscuring the embodiments described. The description is not to be considered as limited to the scope of the embodiments described herein.

The disclosure generally relates to heat exchangers for cooling bulk solids that have a temperature, for example, in the range of about 400° C. to about 2400° C. Examples of bulk solids include metal powders, ash, coke, coals, carbon powders, graphite powders, and other solids that flow under the force of gravity.

FIG. **1** and FIG. **2** show partially cutaway front and rear perspective views of an embodiment of a heat exchanger for cooling bulk solids. The heat exchanger **100** includes a housing **102** with a generally rectangular cross-section. The housing **102** has a top **104** and a bottom **106**. The top **104** of the housing **102** includes an inlet **108** for introducing bulk solids **110** into the heat exchanger **100**, such as bulk solids **110** that have a temperature in the range of about 400° C. to about 2400° C. For example, bulk solids **110** that have a temperature of about 750° C. may be introduced into the heat exchanger **100** through the inlet **108**. The bottom **106** of the housing **102** of the heat exchanger **100** is open to provide an outlet (not shown) for discharging cooled bulk solids from the housing **102** of the heat exchanger **100**. A vertical axis, referred to herein, extends from a center of the inlet **108** to a center of the outlet.

A plurality of heat transfer tubes **112** are disposed within the housing **102**, between the inlet **108** and the outlet. The heat transfer tubes **112** are horizontally spaced apart along an axis that extends transverse to the vertical axis and are arranged generally parallel to each other in rows, referred to herein as a tube bank. In the example shown in FIG. **1** and FIG. **2**, the heat exchanger **100** includes eight tube banks. The eight tube banks are arranged in a stack, referred to herein as tube stack **114**. The tube stack **114** includes a top tube bank **116**, a bottom tube bank **118**, and six intermediate tube banks **120**, **122**, **124**, **126**, **128**, and **130**. For the purpose of the present example, each heat tube bank **116**, **118**, **120**, **122**, **124**, **126**, **128**, **130** includes five heat transfer tubes **112**. Although the heat exchanger **100** of FIG. **1** and FIG. **2** includes eight tube banks, other suitable numbers of tube banks may be utilized. Also, other suitable numbers of heat transfer tubes **112** in each tube bank may be utilized.

The top tube bank **116** of the tube stack **114** (i.e. the heat transfer tube bank that is located closest to the inlet **108**) is sufficiently spaced from the inlet **108** to provide a hopper **132** in the housing **102** between the inlet **108** and the top tube bank **116**. The hopper **132** facilitates distribution of bulk solids **110** that flow from the inlet **108**, as a result of the force of gravity, over the heat transfer tubes **112** of the top tube bank **116** by disbursing the bulk solids **110** over the entire cross-section of the heat exchanger **100** as bulk solids **110** flow from the inlet **108** into the housing **102**.

The heat exchanger **100** also includes a plurality of heat transfer plate assemblies for cooling bulk solids, such as solids that have a temperature between 2400° C. and 400° C., referred herein to as high temperature heat transfer plate assemblies **134**. The high temperature heat transfer plate assemblies **134** are disposed within the housing **102** and interposed between the heat transfer tubes **112** (i.e. the tube stack **114**) and the outlet. The high temperature heat transfer plate assemblies **134** are horizontally spaced apart spaced apart along an axis that extends transverse to the vertical axis and are arranged generally parallel to each other in rows, referred to herein as an assembly bank. In the example shown in FIG. **1** and FIG. **2**, the heat exchanger **100** includes four assembly banks. The four assembly banks are arranged in a stack, referred herein to as an assembly stack **136**. The assembly stack **136** includes a top assembly bank **138**, a bottom assembly bank **140**, and two intermediate assembly banks **142**, **144**. For the purpose of the present example, each assembly bank **138**, **140**, **142**, **144** includes eleven high temperature heat transfer plate assemblies **134**. Although the heat exchanger **100** of FIG. **1** and FIG. **2** includes four assembly banks **138**, **140**, **142**, **144**, other suitable numbers of assembly banks may be utilized. Also, other suitable numbers of high temperature heat transfer plate assemblies **134** in each assembly bank may be utilized.

The heat exchanger **100** also includes a plurality of heat transfer plate assemblies for cooling bulk solids that have a temperature less than 400° C., hereinafter referred to as low temperature heat transfer plate assemblies **146**. The low temperature heat transfer plate assemblies **146** are disposed within the housing **102** and interposed between the high temperature heat transfer plate assemblies **134** (i.e. the assembly stack **136**) and the outlet. The low temperature heat transfer plate assemblies **146** are horizontally spaced apart spaced apart along the axis that extends transverse to the vertical axis and are arranged generally parallel to each other in rows, referred to herein as a bank. In the example shown in FIG. **1** and FIG. **2**, the heat exchanger **100** includes a single bank **148**. For the purpose of the present example, the bank **148** includes seven low temperature heat transfer plate assemblies **146**. Although the heat exchanger **100** of FIG. **1** and FIG. **2** includes a single bank **148**, other suitable numbers of banks **148** may be utilized. Also, other suitable numbers of low temperature heat transfer plate assemblies **146** in the bank **148** may be utilized.

The bank **148** is sufficiently spaced from the outlet to facilitate the flow of bulk solids **110** through the outlet and out of the housing **102**. Optionally, the heat exchanger **100** includes a discharge hopper **150** that is coupled to the housing **102** at the outlet. The discharge hopper **150** is utilized to create a mass flow or "choked flow" of bulk solids and to regulate the flow rate of the bulk solids **110** out of the heat exchanger **100**. An example of a discharge hopper **150** is described in U.S. Pat. No. 5,167,274. The term "choked flow" is utilized herein to refer to a flow other than a free fall of the bulk solids **110** as a result of the force of gravity.

The tube stack **114**, including the eight tube banks **116**, **118**, **120**, **122**, **124**, **126**, **128**, **130**, the assembly stack **136**, including the four assembly banks **138**, **140**, **142**, **144**, and the bank **148**, are supported on support channels **152** at the bottom of the bank **148**. The support channels **152** support the tube stack **114**, the assembly stack **136**, the bank **148**, and the weight of the bulk solids **110** introduced into the heat exchanger **100** as the weight of the bulk solids **110** is transferred to the heat transfer tubes **112**, the high temperature heat transfer plate assemblies **134**, and the low temperature heat transfer plate assemblies **146**.

Referring to FIG. **3**, a top view of the top tube bank **116** of the heat exchanger **100** of FIG. **1** is shown. Each heat transfer tube **112** of the top tube bank **116** extends a width of the housing **102** between the first side wall **302** and an opposing second side wall **304** of the housing **102**. A first end **306** of each heat transfer tube **112** passes through an opening (not shown) in the first side wall **302** of the housing **102** such that the first end **306** extends out of the housing **102**. A second end **308** of each heat transfer tube **112** passes through an opening (not shown) in the second side wall **304** of the housing **102** such that the second end **308** extends out of the housing **102**. The heat transfer tubes **112** of the top tube bank **116** are arranged generally parallel to each other with spaces between adjacent heat transfer tubes **112**. Each space between adjacent heat transfer tubes **112** defines a passageway **310** for bulk solids **110** to flow through. Optionally, a heat resistant lining **312** may be disposed between a third side wall **314** of the housing **102**, and the heat transfer tube **112** located adjacent to or near the third side wall **314**. A heat resistant lining **312** may also be disposed between a fourth side wall **316** of the housing **102** and the heat transfer tube **112** located adjacent to or near a fourth side wall **316**. The fourth side wall **316** is opposite the third side wall **314**. Also, a water-jacket skin **318** may be disposed on an outer surface of the third side wall **314** and an outer surface of the fourth side wall **316**. The heat resistant lining **312** is utilized to protect the water-jacket skin **318**, for example, in areas of the water-jacket skin **318** in which water flow is not sufficient.

The heat resistant lining **312** may be made from any suitable material to withstand the temperatures of the bulk solids and that has sufficient mechanical strength to withstand flow of the bulk solids. Examples of materials for the heat resistant lining **312** include graphite or any other suitable insulating material, such as a refractory board or other fibrous or foam type board. The water-jacket skin **318** may be made from any suitable material, such as Type 314L stainless steel or Type 316L stainless steel. The bottom tube bank **118** and the six intermediate tube banks **120**, **122**, **124**, **126**, **128**, and **130** have a similar configuration as the top tube bank **116**.

Referring to FIG. **4**, an end view of the tube stack **114** of the heat exchanger **100** of FIG. **1** is shown. The heat transfer tubes **112** of the top tube bank **116**, and the heat transfer tubes **112** of the second, fourth, and sixth intermediate tube banks **122**, **126**, **130** are arranged such that the heat transfer tubes **112** of the top tube bank **116**, and the heat transfer tubes **112** of the second, fourth and sixth intermediate tube banks **122**, **126**, **130**, are vertically aligned in columns. The heat transfer tubes **112** of the first, third, and fifth intermediate tube banks **120**, **124**, **128**, and the bottom tube bank **118** are also arranged such that the heat transfer tubes **112** of the first, third, and fifth intermediate tube banks **120**, **124**, **128**, and the heat transfer tubes **112** of the bottom tube bank **118** are vertically aligned in columns.

The first, third, and fifth intermediate tube banks **120**, **124**, **128**, and the bottom tube bank **118** are vertically and horizontally offset from the top tube bank **116** and the second, fourth, and sixth intermediate tube banks **122**, **126**, **130** such that the heat transfer tubes **112** of the first, third, and fifth intermediate tube banks **120**, **124**, **128**, and the bottom tube bank **118** are not vertically aligned and not horizontally aligned with the heat transfer tubes **112** of the top tube bank **116** and the second, fourth and sixth intermediate tube banks **122**, **126**, **130**. Passageways **310** are provided between the heat transfer tubes **112** of the top tube bank **116**, the heat transfer tubes of the first, second, third, fourth, fifth, and six intermediate tube banks **120**, **122**, **124**, **126**, **128**, **130**, and the heat transfer tubes **112** of the bottom tube bank **118** for bulk solids **110** to flow through.

The heat transfer tubes **112** of the first, third, and fifth intermediate tube banks **120**, **124**, **128** and the heat transfer tubes **112** of the bottom tube bank **118** may be horizontally and vertically offset from the heat transfer tubes **112** of the top tube bank **116** and the heat transfer tubes **112** of the second, fourth and sixth intermediate tube banks **122**, **126**, **130** such that the heat transfer tubes **112** of the first, third, and fifth intermediate tube banks **120**, **124**, **128** and the heat transfer tubes **112** of the bottom tube bank **118** are horizontally and vertically spaced by a suitable distance to facilitate the cooling zones between adjacent heat transfer tubes **112**. For example, the heat transfer tubes **112** of the first, third, and fifth intermediate tube banks **120**, **124**, **128** and the heat transfer tubes **112** of the bottom tube bank **118** are horizontally spaced by a horizontal distance that is half of the distance between adjacent heat transfer tubes **112** of the top tube bank **116**, and vertically spaced by a distance that is half of the distance from a heat transfer tube **112** in the top tube bank **116** to an adjacent heat transfer tube **112** in the second intermediate tube bank **120**.

Alternatively, the heat transfer tubes **112** of the top tube bank **116**, the first intermediate tube bank **120**, the second intermediate tube bank **122**, the third intermediate tube bank **124**, the fourth intermediate tube bank **126**, the fifth intermediate tube bank **128**, the sixth intermediate tube bank **130**, and the bottom tube bank **118** may be horizontally aligned in rows and vertically aligned in columns such that the passageways **310** extend through the entire tube stack **114**.

The terms top, bottom, horizontal, and vertical are utilized herein to provide reference to the orientation of the heat exchanger **100** when assembled for use, as shown in FIG. **1**. The term heat transfer tube is utilized herein to refer to a conduit through which fluid may flow. The heat transfer tube **112** is not limited to a cylindrical tube and may be any other suitable shape to facilitate fluid flow therethrough.

Referring again to FIG. **1** and FIG. **2**, the heat exchanger **100** also includes a tube inlet manifold **154** for providing cooling fluid into each heat transfer tube **112** of the top tube bank **116**, and into each heat transfer tube **112** of the first intermediate tube bank **120**. The tube inlet manifold **154** is coupled to the housing **102** and is in fluid communication with each heat transfer tube **112** of the top tube bank **116** and each heat transfer tube **112** of the first intermediate tube bank **120**. A respective fluid line **158** extends from the first end **306** of a respective heat transfer tube **112** of the top tube bank **116** to the tube inlet manifold **154**. A respective fluid line **160** also extends from the first end **306** of a respective heat transfer tube **112** of the first intermediate tube bank **120** to the tube inlet manifold **154**.

The heat exchanger **100** also includes a tube discharge manifold **156** for receiving cooling fluid discharged from each of heat transfer tube **112** of the sixth intermediate tube bank **130**, and from each of heat transfer tube **112** of the bottom tube bank **118**. The tube discharge manifold **156** is coupled to the housing **102** and is in fluid communication with each heat transfer tube **112** of the sixth intermediate tube bank **130**, and each heat transfer tube **112** of the bottom tube bank **118**. A respective fluid line **162** extends from the first end **306** of a respective heat transfer tube **112** of the sixth intermediate tube bank **130** to the tube discharge manifold **156**. A respective fluid line **164** also extends from the first end **306** of a respective heat transfer tube **112** of the bottom tube bank **118** to the tube discharge manifold **156**.

The cooling fluid may be any suitable fluid that transfers heat from bulk solids **110** that flow between adjacent heat transfer tubes **112**, for example, water or thermal oil.

The heat transfer tubes **112** of the top tube bank **116**, the second intermediate tube bank **122**, the fourth intermediate tube bank **126**, and the sixth intermediate tube bank **130** are arranged in columns and in fluid communication with each other in a serpentine manner. A respective fluid line **166** extends from the second end **308** of a respective heat transfer tube **112** of the top tube bank **116** to the second end **308** of a respective heat transfer tube **112** of the second intermediate tube bank **122**. Similarly, a respective fluid line **168** extends from the first end **306** of a respective heat transfer tube **112** of the second intermediate tube bank **122** to the first end **306** of a respective heat transfer tube **112** of the fourth intermediate tube bank **126**, and a respective fluid line **170** extends from the second end **308** of a respective heat transfer tube **112** of the fourth intermediate tube bank **126** to the second end **308** of a respective heat transfer tube **112** of the sixth intermediate tube bank **130**.

The heat transfer tubes **112** of the first intermediate tube bank **120**, the third intermediate tube bank **124**, the fifth intermediate tube bank **128**, and the bottom tube bank **118** are also arranged in columns and in fluid communication with each other in a serpentine manner. A respective fluid line **172** extends from the second end **308** of a respective heat transfer tube **112** of the first intermediate tube bank **120** to the second end **308** of a respective heat transfer tube **112** of the third intermediate tube bank **124**. Similarly, a respective fluid line **174** extends from the first end **306** of a respective heat transfer tube **112** of the third intermediate tube bank **124** to the first end **306** of a respective heat transfer tube **112** of the fifth intermediate tube bank **128**, and a respective fluid line **176** extends from the second end **308** of a respective heat transfer tube **112** of the fifth intermediate tube bank **128** to the second end **308** of a respective heat transfer tube **112** of the bottom tube bank **118**.

Referring to FIG. **5**, a side view of a portion of the heat exchanger **100** of FIG. **1** is shown, in which a first end **306** of a heat transfer tube **112** of the top tube bank **116** is coupled to an end **502** of a fluid line **158** by a seal **500**. As shown in FIG. **5**, the first end **306** of the heat transfer tube **112** passes through an opening in the first side wall **302** of the housing **102** and extends therethrough. The seal **500** facilitates movement of the heat transfer tube **112** within the housing **102** when cooling fluid flows from the respective fluid line **158** into the heat transfer tube **112** under high pressure.

Referring to FIG. **6**, an exploded perspective view of an example of the seal **500** is shown. The seal **500** includes a high temperature gasket **602**, a packing collar **604**, a high temperature packing **606**, a sealing washer **608**, a first backing washer **610**, a compression spring **612**, and a second backing washer **614**. The high temperature gasket **602** forms a seal against the first sidewall **302** of the housing **102** of the heat exchanger **100** to inhibit any bulk solids **110** from being discharged from the housing **102** through a gap (not shown) between the heat transfer tube **112** and the opening in the first sidewall **302** through which the end **306** of the heat transfer tubes **112** passes through. The high temperature packing **606** seals against an outer surface of the heat transfer tube **112** to also inhibit any bulk solids **110** from discharging from the housing **102** through the gap between the heat transfer tube **112** and the opening in the first sidewall **302** of the housing **102**. The sealing washer **608** holds the high temperature packing **606** in place and ensures that the heat transfer tube **112** is centered in the packing collar **604**. The first backing washer **610** transfers pressure from the compression spring **612** to the packing collar **604**, and in turn to the high temperature gasket **602** and the first sidewall **302**, as cooling fluid flows through the heat transfer tube **112**. The second backing washer **614** acts as a backing for the compression spring **612** against the respective fluid line **158**.

The seal **500** is a leak resistant seal between the first end **306** of a heat transfer tube **112** and a respective fluid line **158** to inhibit leakage when a cooling fluid flows either into or from a first end **306** of the heat transfer tube **112**.

In the example shown in FIG. **1** and FIG. **2**, the first end **306** of each heat transfer tube **112** of the top tube bank **116** is coupled to an end **502** of a respective fluid line **158** by a seal **500**. The second end **308** of each heat transfer tube **112** of the top tube bank **116** is also coupled to a second end of a respective fluid line **158** by a seal **500**. Similarly, the first end **306** of each heat transfer tube **112** of the tube banks **118**, **120**, **122**, **124**, **126**, **128**, and **130** are coupled to a first end **502** of the respective fluid lines **164**, **160**, **168**, **174**, **162** by a seal **500**. Also, the second end **308** of each heat transfer tube **112** of the tube banks **118**, **120**, **122**, **124**, **126**, **128**, **130** are coupled to a second end of the respective fluid lines **176**, **166**, **172**, and **170** by a seal **500**.

The flow of cooling fluid through the tube stack **114** will now be described with reference to FIG. **1** and FIG. **2**. In operation, cooling fluid flows from the tube inlet manifold **154** to the tube discharge manifold **156** in a serpentine manner such that the cooling fluid flows from the tube inlet manifold **154**, into the respective fluid lines **158**, **160**, through the heat transfer tubes **112** of the top tube bank **116** and the first intermediate tube bank **120**, into the respective fluid lines **166**, **172**, through the heat transfer tubes **112** of the second intermediate tube bank **122** and the third intermediate tube bank **124**, and into the respective fluid lines **168**, **174**. The cooling fluid then flows through the heat transfer tubes **112** of the fourth intermediate tube bank **126** and the fifth intermediate tube bank **128**, into the respective fluid lines **170**, **176**, through the heat transfer tubes **112** of the sixth intermediate tube bank **130** and the bottom tube bank **118**, into the respective fluid lines **162**, **164**, and into the tube discharge manifold **156**.

Although the flow of cooling fluid has been described herein as flowing in a downward direction through the tube stack **114**, in an alternative embodiment, the tube inlet manifold **154** may be a tube discharge manifold, the tube discharge manifold **156** may be a tube inlet manifold, and the direction of flow of the cooling fluid through the tube stack **114** and the heat transfer tubes **112** may be in an opposite direction to that described such that the cooling fluid flows upwardly through the tube stack **114**.

Referring to FIG. **7**, a top view of the top assembly bank **138** of the heat exchanger **100** of FIG. **1** is shown. Each high temperature heat transfer plate assembly **134** of the top assembly bank **138** extends the width of the housing **102** between the first side wall **302** of the housing **102** and the opposing second side wall **304** of housing **102**. The high temperature heat transfer plate assemblies **134** are arranged generally parallel to each other with spaces between adjacent high temperature heat transfer plate assemblies **134**. Each space between adjacent high temperature heat transfer plate assemblies **134** defines a passageway **702** for bulk solids **110** to flow through. Optionally, insulation **704** may be disposed between a third side wall **314** of the housing **102** and the high temperature heat transfer plate assembly **134** located adjacent to the third side wall **314**. Insulation **704** may also be disposed between the fourth side wall **316**, and the high temperature heat transfer plate assembly **134** located adjacent to or near the fourth sidewall **316**. The insulation **704** may be a ceramic fiber sheet of suitable thickness that inhibits the flow of bulk solids **110** in the space between the third side wall **314** and the adjacent high temperature heat transfer plate assembly **134**, and the space between the fourth side wall **316** and the adjacent high temperature heat transfer plate assembly **134**, respectively.

Alternatively, a high temperature heat resistant lining **312** as shown in FIG. **3** and described above may be disposed between the third side wall **314** of the housing **102** and the high temperature heat transfer plate assembly **134** located adjacent to or near the third side wall **314**, and the water-skin jacket **318** may be disposed on the outer surface of the third side wall **314**. The high temperature heat resistant lining **312** may also be disposed between the fourth side wall **316** and the high temperature heat transfer plate assembly **134** located adjacent to or near the fourth sidewall **316** and the water-skin jacket **318** may also be disposed on the outer surface of the fourth side wall **316**.

The bottom assembly bank **140** and the first and second intermediate assembly banks **142**, **144** have a similar configuration as the top assembly bank **138**.

The four assembly banks **138**, **140**, **142**, and **144** of high temperature heat transfer plate assemblies **134** may be vertically aligned in columns in the housing **102** such that the passageways **702** extend through the entire assembly stack **136**. Alternatively, the high temperature heat transfer plate assemblies **134** in the four assembly banks **138**, **140**, **142**, and **144** may be arranged such that the high temperature heat transfer plate assemblies **134** are horizontally offset from one another.

A perspective view of an example of a high temperature heat transfer plate assembly **134** is shown in FIG. **8**. The high temperature heat transfer plate assembly **134** includes a heat transfer plate **802**, a first fluid conduit **804**, and a second fluid conduit **806**, and a pipe **808**. The term pipe is utilized herein to refer to a conduit through which fluid may flow. The pipe **808** is not limited to a cylindrical pipe and may be any other suitable shape to facilitate fluid flow therethrough.

The heat transfer plate **802** includes a pair of metal sheets **810**. The sheets **810** may be made from stainless steel, such as 316L stainless steel. The two sheets of the pair of sheets **810** are arranged generally parallel to each other. The two sheets are welded together at locations on each sheet and also seam welded along the bottom edges of the two sheets. After the two sheets **810** are welded together, the sheets are inflated such that generally circular depressions **812** are formed on each sheet. The generally circular depressions **812** are distributed throughout each sheet and are located at complementary locations on each sheet such that the generally circular depressions **812** on one of the sheets are generally aligned with the depressions **812** on the other of the sheets. When the sheets **810** are inflated, spaces are provided between the sheets **810** in areas where the sheets **810** are not welded together.

The first fluid conduit **804** extends along a first side edge **814** of the heat transfer plate **802**, at least between a top end **816** and a bottom end **818** of the heat transfer plate **802**. The first fluid conduit **804** is welded to the first side edge **814** of each of the sheets **810**. The second fluid conduit **806** extends along an opposing second side edge **820** of the heat transfer plate **802**, at least between the top end **816** and the bottom end **818** of the heat transfer plate **802**. The second fluid conduit **806** is welded to the second side edge **820** of each of the sheets **810**.

The pipe **808** extends along the top end **816** of the heat transfer plate **802**. A first end **822** of the pipe **808** is in fluid communication with the first fluid conduit **804**. The pipe **808** passes through the second fluid conduit **806**. The pipe **808** may be in fluid communication with a top portion **910** (shown in FIG. **9**) of the second fluid conduit **806**. A second end **824** of the pipe **808** extends from the second fluid conduit **806** to provide a cooling fluid inlet. The pipe **808** is welded to the top edge of each of the sheets **810**. The pipe **808** may have a diameter that is greater than or equal to the thickness of the heat transfer plate **802**.

The high temperature heat transfer plate assembly **134** also includes a cooling fluid outlet **826**. The cooling fluid outlet **826** extends substantially perpendicular to and away from the second fluid conduit **806**. The cooling fluid outlet **826** is in fluid communication with the second fluid conduit **806**.

In the example embodiment shown in FIG. **8**, the cooling fluid outlet **826** is located near the bottom end **818** of the heat transfer plate **802**. Alternatively, the cooling fluid outlet **826** may be located any suitable distance from the bottom end **818** of the heat transfer plate **802**. For example, the cooling fluid outlet **826** may be located near the middle of the second fluid conduit **806**.

The first fluid conduit **804** and the second fluid conduit **806** have diameters that are larger than the diameter of the pipe **808**. When the high temperature heat transfer plate assemblies **134** are arranged in an assembly bank, the first fluid conduits **804** of adjacent high temperature heat transfer plate assemblies **134** abut each other and the second fluid conduits **806** of adjacent high temperature plate assemblies **134** abut each other, as shown in FIG. **7**. The diameters of the first and second fluid conduits **804**, **806** may be larger than the diameter of the pipe **808** to space apart the high temperature heat transfer plates **802** of adjacent high temperature heat transfer plate assemblies **134** when the high temperature heat transfer plate assemblies **134** are arranged in a bank. Alternatively, the high temperature heat transfer plate assemblies **134** may be arranged in an assembly bank such that the first fluid conduits **804** of adjacent heat transfer plate assemblies **134** are horizontally offset. For example, the first fluid conduits **804** of the first, third, fifth, seventh, ninth, and eleventh high temperature heat transfer plate assemblies **134** may be horizontally offset from the first fluid conduits **804** of the second, fourth, sixth, eighth, and tenth high temperature heat transfer plate assemblies **134** such that the first fluid conduits **804** of the first, third, fifth, seventh, ninth, and eleventh high temperature heat transfer plate assemblies **134** are not horizontally aligned with the first fluid conduits **804** of the second, fourth, sixth, eighth, and tenth high temperature heat transfer plate assemblies **134**.

When the four assembly banks **138**, **140**, **142**, and **144** are arranged in an assembly stack **136**, the first fluid conduits **804** of one assembly bank may be aligned with the first fluid conduits **804** of the assembly bank that is directly below such that the first fluid conduits **804** of the lower assembly bank support the first fluid conduits **804** of the upper assembly bank. Similarly, the second fluid conduits **806** of the lower assembly bank support the second fluid conduits **806** of the upper assembly bank. Thus, a respective first fluid conduit **804** of a high temperature heat transfer plate assembly **134** of the top assembly bank **138** is disposed on a respective first fluid conduit **804** of a high temperature heat transfer plate assembly **134** of the first intermediate assembly bank **142**, and a respective second fluid conduit **806** of a high temperature heat transfer plate assembly **134** of the top assembly bank **138** is disposed on a respective second fluid conduit **806** of a high temperature heat transfer plate assembly **134** of the first intermediate assembly bank **142**. Similarly, a respective first fluid conduit **804** of a high temperature heat transfer plate assembly **134** of the first intermediate assembly bank **142** is disposed on a respective first fluid conduit **804** of a high temperature heat transfer plate assembly **134** of the second intermediate assembly bank **144**, and a respective second fluid conduit **806** of a high temperature heat transfer plate assembly **134** of the first intermediate assembly bank **142** is disposed on a respective second fluid conduit **806** of a high temperature heat transfer plate assembly **134** of the second intermediate assembly bank **144**.

Similarly, a respective first fluid conduit **804** of a high temperature heat transfer plate assembly **134** of the second intermediate assembly bank **144** is disposed on a respective first fluid conduit **804** of a high temperature heat transfer plate assembly **134** of the bottom assembly bank **140**, and a respective second fluid conduit **806** of a high temperature heat transfer plate assembly **134** of the second intermediate assembly bank **144** is disposed on a respective second fluid conduit **806** of a high temperature heat transfer plate assembly **134** of the bottom assembly bank **140**.

Referring to FIG. **9**, a sectional view of the high temperature heat transfer plate assembly **134** of FIG. **8** is shown. The first fluid conduit **804** includes openings **902** into the heat transfer plate **802**. The openings **902** are distributed along the first fluid conduit **804** at the first side **814** of the high temperature heat transfer plate **802**. The openings **902** may be unevenly distributed such that the openings **902** are more closely spaced near the top of the first fluid conduit **804**. Alternatively, the openings **902** may be larger near the top of the first fluid conduit **804**. The second fluid conduit **806** includes openings **904** into the high temperature heat transfer plate **802**. The openings **904** are distributed along the second fluid conduit **806** at the second side **820** of the heat transfer plate **802**. The openings **904** may be unevenly distributed such that the openings **904** are more closely spaced near the top of the second fluid conduit **806**. Alternatively, the openings **904** may be larger near the top of the second fluid conduit **806**. The pipe **808** also includes an opening **908** to a top portion **910** of the second fluid conduit **806** to provide cooling fluid to the top portion **910** of the second fluid conduit **806**.

The cooling fluid enters the top portion **910** of the second fluid conduit **806** through opening **908**. The cooling fluid also enters the top portion **912** of the first fluid conduit **804**. The top portion **910** of the second fluid conduit **806** and the top portion **912** of the first fluid conduit **804** may be sized to inhibit overheating of the top portions **910**, **912**. Thus, the top portions **910**, **912** of the first and second fluid conduits **804**, **806** are short enough to facilitate fluid flow and cooling of the top portions **910**, **912**. Additionally, fluid may flow through the top portions **910**, **912** of the first and second fluid conduits **804**, **806** to further cool the top portions **910**, **912**. To facilitate flow of cooling fluid, the outside diameter of the pipe **808** is sufficiently less than the inside diameter of the second fluid conduit **806** for fluid to flow from the top portion **910** into a lower portion of the second fluid conduit **806**. With sufficient fluid flow, the top portions **910**, **912** may be longer and spacing between the assembly banks **138**, **140**, **142**, **144** that are arranged in the assembly stack **136** may be increased.

Referring again to FIG. **1** and FIG. **2**, the heat exchanger **100** also includes a fluid inlet manifold **178** for providing cooling fluid into each high temperature heat transfer plate assembly **134** of the top assembly bank **138**. The heat exchanger **100** also includes a fluid discharge manifold **180** for receiving cooling fluid discharged from each high temperature heat transfer plate assembly **134** of the bottom assembly bank **140**. The fluid inlet manifold **178** is coupled to the housing **102** and is in fluid communication with each high temperature heat transfer plate assembly **134** of the top assembly bank **138**. A respective fluid line **182** extends from each high temperature heat transfer plate assembly **134** of the top assembly bank **138** to the first fluid inlet manifold **178**. The fluid discharge manifold **180** is coupled to the housing **102** and is in fluid communication with each high temperature heat transfer plate assembly **134** of the bottom assembly bank **140**. A respective fluid line **184** extends from each high temperature heat transfer plate assembly **134** of the bottom assembly bank **140** to the first fluid discharge manifold **180**. The cooling fluid may be any suitable fluid that transfers heat from bulk solids **110** that flow between adjacent high temperature heat transfer plate assemblies **134**, for example water or thermal oil.

In the example of FIG. **1** and FIG. **2**, the high temperature heat transfer plate assemblies **134** of the top assembly bank **138**, the bottom assembly bank **140**, and the two intermediate assembly banks **142**, **144** are arranged in columns. The high temperature heat transfer plate assemblies **134** of each column are in fluid connection with each other. For example, a respective fluid line **186** extends from each high temperature heat transfer plate assembly **134** of the top assembly bank **138** to a respective heat transfer plate assembly **134** of the first intermediate assembly bank **142** of the same column. A respective fluid line **188** extends from each high temperature heat transfer plate assembly **134** of the first intermediate assembly bank **142** to a respective high temperature heat transfer plate assembly **134** of the second intermediate assembly bank **144** of the same column. A respective fluid line **190** extends from each high temperature heat transfer plate assembly **134** of the second intermediate assembly bank **144** to a respective high temperature heat transfer plate assembly **134** of the bottom assembly bank **140** of the same column.

The flow of cooling fluid through the assembly stack **136** will now be described with reference to FIG. **1**, FIG. **8**, and FIG. **9**. The flow of the cooling fluid through a high temperature heat transfer plate assembly **134** is illustrated by the arrows in FIG. **9**. In operation, cooling fluid flows from the fluid inlet manifold **178** through the respective fluid lines **182** into the respective pipes **808** of the high temperature heat transfer plate assemblies **134** of the top assembly bank **138**. For the purposes of this example, the flow of cooling fluid through one of the high temperature heat transfer plate assemblies **134** will be described with reference to FIG. **9**.

The cooling fluid flows through the pipe **808** of the high temperature heat transfer plate assembly **134** into the first fluid conduit **804**. Cooling fluid also flows from the pipe **808**, through the opening **908**, and into the top portion **910** of the second fluid conduit **806**. From the first fluid conduit **804**, the cooling fluid flows into the heat transfer plate **802** through the openings **902**. The cooling fluid flows through the heat transfer plate **802** into the second fluid conduit **806**, through the openings **904** in the second fluid conduit **806**. The generally circular depressions **812** distributed throughout the heat transfer plate **802** facilitate the flow of the cooling fluid throughout the heat transfer plate **802**. The cooling fluid then flows from the second fluid conduit **806** into the cooling fluid outlet **826**. The cooling fluid that flows through the assembly stack **136** may be the same cooling fluid that flows though tube stack **114**. Alternatively, the cooling fluid that flows through the high temperature assembly stack **136** may be a different cooling fluid than the cooling fluid that flows through tube stack **114**.

Referring again to FIG. **1**, FIG. **8**, and FIG. **9**, the cooling fluid flows from the cooling fluid outlet **826** of each high temperature heat transfer plate assembly **134** of the top assembly bank **138**, through the respective fluid lines **186**, and into the respective pipes **808** of the heat transfer plate assemblies **134** of the first intermediate assembly bank **142**. The cooling fluid flows through each high temperature heat transfer plate assembly **134** of the first intermediate assembly bank **142** in a similar manner as described above.

The cooling fluid then flows from the cooling fluid outlet **826** of the high temperature heat transfer plate assemblies **134** of the first intermediate high temperature heat transfer plate assembly bank **142**, through the respective fluid lines **188**, and into the respective pipes **808** of the high temperature heat transfer plate assemblies **134** of the second intermediate bank **144**. The cooling fluid flows through each high temperature heat transfer plate assembly **134** of the second intermediate bank **144** in a similar manner as described above.

The cooling fluid then flows from the cooling fluid outlet **826** of the high temperature heat transfer plate assemblies **134** of the second intermediate assembly bank **144** through the respective fluid lines **190**, and into the respective pipes **808** of the high temperature heat transfer plate assemblies **134** of the bottom assembly bank **140**. The cooling fluid flows through each high temperature heat transfer plate assembly **134** of the bottom assembly bank **140** in a similar manner as described above.

The cooling fluid flows from the cooling fluid outlet **826** of each high temperature heat transfer plate assembly **134** of the bottom assembly bank **140** through the respective fluid lines **184**, and into the fluid discharge manifold **180**.

Although the flow of cooling fluid has been described herein as flowing in a downward direction through the assembly stack **136**, in an alternative embodiment the fluid inlet manifold **178** may be a fluid discharge manifold, the fluid discharge manifold **180** may be a fluid inlet manifold, and the direction of flow of cooling fluid through the assembly stack **136** and the high temperature heat transfer plate assemblies **134** may be in an opposite direction to that described such that the cooling fluid flows upwardly through the assembly stack **136**.

Referring to FIG. **10**, a top view of the bank **148** of the heat exchanger **100** of FIG. **1** is shown. Each low temperature heat transfer plate assembly **146** of the bank **148** extends the width of the housing **102** between the first side wall **302** of the housing **102** and the opposing second side wall **304** of the housing **102**. The low temperature heat transfer plate assemblies **146** are arranged generally parallel to each other with spaces between adjacent low temperature heat transfer plate assemblies **146**. Each space between adjacent low temperature heat transfer plate assemblies **146** defines a passageway **1002** for bulk solids **110** to flow through.

A sectional view of an example of a low temperature heat transfer plate assembly **146** is shown in FIG. **11**. The low temperature heat transfer plate assembly **146** includes a pair of metal sheets **1102**, a fluid inlet **1104**, and a fluid outlet **1106**. The sheets **1102** may be made from stainless steel, such as 316L stainless steel. Each sheet **1102** includes a top edge **1108**, a bottom edge **1110**, a front side edge **1112**, and an opposing rear side edge **1114**.

The low temperature heat transfer plate assembly **146** may be assembled by, for example, arranging the pair of sheets **1102** generally parallel to each other. The sheets are welded together at locations distributed over the sheets and are seam welded along the top edges **1108**, the opposing rear side edges **1114**, and the bottom edges **1110** of the two sheets **1102**. After the two sheets **1102** are welded together, slots are cut for insertion of nozzles that are welded to the sheets and are utilized as a fluid inlet **1104** and a fluid outlet **1106**. The sheets **1102** are inflated utilizing the nozzles such that generally circular depressions **1116** are formed on each sheet. The generally circular depressions **1116** are distributed throughout each sheet and are located at complementary locations on each sheet such that the depressions **1116** on one of the sheets are generally aligned with the depressions **1116** on the other of the sheets. When the sheets **1102** are inflated, spaces are provided between the sheets **1102** in areas where the sheets **1102** are not welded together to facilitate fluid flow through the sheets **1102**.

The fluid inlet **1104** extends from the front side edge **1112** of the sheets **1102** at a location near the top edge **1108** of the sheets **1102**. The fluid outlet **1106** extends the front side edge **1112** of the sheets **1102** at a location near the bottom edge **1110** of the sheets **1102**.

Referring again to FIG. **1** and FIG. **2**, the heat exchanger **100** also includes an inlet manifold **192** for providing cooling fluid into each low temperature heat transfer plate assembly **146** of the bank **148** and a discharge manifold **194** for receiving cooling fluid discharged from each low temperature heat transfer plate assembly **146** of the bank **148**. The inlet manifold **192** is coupled to the housing **102** and is in fluid communication with each low temperature heat transfer plate assembly **146** of the bank **148**. A respective fluid line **196** extends from the inlet manifold **192** to a fluid inlet **1104** of each low temperature heat transfer plate assembly **146** of the bank **148**. A respective fluid line **198** also extends from the discharge manifold **194** to a cooling fluid outlet **1106** of each heat transfer plate assembly **146** of the bank **148** as described in further detail below with reference to FIG. **11**.

The flow of cooling fluid through the bank **148** will now be described with reference to FIG. **1**, FIG. **2**, and FIG. **11**. The flow of the cooling fluid through a low temperature heat transfer plate assembly **146** is illustrated by the arrows in FIG. **11**. In operation, cooling fluid flows from the inlet manifold **192** through the respective fluid lines **196**, through the fluid inlet **1104** and into each low temperature heat transfer plate assemblies **146** of the bank **148**. The cooling fluid then flows through each low temperature heat transfer plate assembly **146**, through the fluid outlet **1106**, through the respective fluid lines **198**, and into the discharge manifold **194**.

In an alternative embodiment, the direction of flow of cooling fluid through each low temperature heat transfer plate assembly **146** may be in an opposite direction to that described such that the cooling fluid flows from the discharge manifold **194**, through the respective fluid lines **198**, into the fluid outlets **1106**, through each low temperature heat transfer plate assembly **146**, into the fluid inlets **1104**, through the respective fluid lines **196**, and back into the inlet manifold **192**.

In the example shown in FIG. **1** and FIG. **2**, the eight tube banks **116**, **118**, **120**, **122**, **124**, **126**, **128**, **130**, the four assembly banks **138**, **140**, **142**, **144**, and the single bank **148** are arranged in the housing **102** such that the passageways **310**, **702**, **1002** are aligned and extend through the entire tube stack **114**, the entire assembly stack **136**, and the bank **148** to facilitate the flow of bulk solids **110** through the heat exchanger **100** from the inlet **108** to the outlet.

The operation of the heat exchanger **100** will now be described with reference to FIG. **1**. When bulk solids **110** that have a starting temperature in the range of, for example, about 400° C. to about 2400° C. are fed into the housing **102**, through the inlet **108**, the bulk solids **110** flow downwardly as a result of the force of gravity from the inlet **108** into the hopper **132**. The hopper **132** facilitates distribution of the bulk solids **110** into the top tube bank **118** as described above. The bulk solids **110** flow through passageways **310**, and bulk solids **110** that contact the heat transfer tubes **112** are deflected into the passageways **310**.

As the bulk solids **110** flow through the passageways **310**, the bulk solids **110** are cooled to a first intermediate temperature as the heat from the bulk solids **110** is transferred to the heat transfer tubes **112** and to the cooling fluid. The bulk solids may be cooled to a first intermediate temperature of, for example, about 750° C. The cooling fluid that flows through the heat transfer tubes **112** indirectly cools bulk solids **110** to the first intermediate temperature.

After initial cooling of the bulk solids **110** to the first intermediate temperature by the heat transfer tubes **112**, the bulk solids **110** that flow through passageways **310** flow towards the passageways **702**. Bulk solids **110** that contact the high temperature heat transfer plate assemblies **134** are deflected into the passageways **702**.

As the bulk solids **110** that have the first intermediate temperature flow through passageways **702**, the bulk solids **110** are further cooled to a second intermediate temperature of, for example, about 400° C. The cooling fluid that flows through the high temperature heat transfer plate assemblies **134** indirectly cools bulk solids **110** to the second intermediate temperature.

After cooling of the bulk solids **110** to the second intermediate temperature by the high temperature heat transfer plate assemblies **134**, the bulk solids **110** that flow through passageways **702** flow towards the passageways **1002**. Bulk solids **110** that contact the low temperature heat transfer plate assemblies **146** are deflected into the passageways **1002**.

As the bulk solids **110** that have the second intermediate temperature flow through passageways **1002**, the bulk solids **110** are further cooled to a cooled temperature of, for example 100° C. The cooling fluid that flows through the low temperature heat transfer plate assemblies **146** indirectly cools bulk solids **110** to the resulting temperature.

The bulk solids **110** then flow from the passageways **1002**, through the outlet, and into the discharge hopper **112**, where the cooled bulk solids **110** are discharged under a "choked" flow.

Although the heat exchanger **100** shown in FIGS. **1** and **2** includes a tube stack **114**, an assembly stack **136**, and a single bank **148**, in an alternative embodiment the heat exchanger **100** may include a tube stack **114** and an assembly stack **136**. In this embodiment, the passageways **310** and **702** are vertically aligned such that bulk solids **110** flow through the heat exchanger **100** from the inlet **108**, through the passageways **310** and **702**, to the outlet. When bulk solids **110** that have a starting temperature in the range of, for example, about 400° C. to about 2400° C. are fed into the housing **102**, through the inlet **108**, the bulk solids **110** flow through the passageways **310**, and the bulk solids **110** are cooled to an intermediate temperature as the heat from the bulk solids **110** is transferred to the heat transfer tubes **112** and to the cooling fluid. After initial cooling of the bulk solids **110** to the intermediate temperature by the heat transfer tubes **112**, the bulk solids **110** that flow through passageways **310** flow towards the passageways **702** and the bulk solids **110** that contact the high temperature heat transfer plate assemblies **134** are deflected into the passageways **702**. As the bulk solids **110** that have the first intermediate temperature flow through passageways **702**, the bulk solids **110** are further cooled to a resulting temperature of, for example, about 400° C. The cooling fluid that flows through the high temperature heat transfer plate assemblies **134** indirectly cools bulk solids **110** to the resulting temperature. The bulk solids **110** then flow from the passageways **702**, through the outlet, and into the discharge hopper **112**, where the cooled bulk solids **110** are discharged under a "choked" flow.

In other embodiments, the heat exchanger **100** may include a tube stack **114** and a single bank **148** or multiple banks of low temperature heat transfer plate assemblies **146**. In these embodiments, the passageways **310** and **1002** are vertically aligned such that bulk solids **110** flow through the heat exchanger **100** from the inlet **108**, through the passageways **310** and **1002**, to the outlet. When bulk solids **110** that have a starting temperature in the range of, for example, about 400° C. to about 2400° C. are fed into the housing **102**, through the inlet **108**, the bulk solids **110** flow through the passageways **310**, and the bulk solids **110** are cooled to an intermediate temperature as the heat from the bulk solids **110** is transferred to the heat transfer tubes **112** and to the cooling fluid. After initial cooling of the bulk solids **110** to the intermediate temperature by the heat transfer tubes **112**, the bulk solids **110** that flow through passageways **310** flow towards the passageways **1002**. Bulk solids **110** that contact the low temperature heat transfer plate assemblies **146** are deflected into the passageways **1002**. As the bulk solids **110** that have the first intermediate temperature flow through passageways **1002**, the bulk solids **110** are further cooled to a resulting temperature of, for example, about 400° C. The cooling fluid that flows through the low temperature heat transfer plate assemblies **146** indirectly cools bulk solids **110** to the resulting temperature. The bulk solids **110** then flow from the passageways **1002**, through the outlet, and into the discharge hopper **112**, where the cooled bulk solids **110** are discharged under a "choked" flow.

Advantageously, the heat transfer tubes of the heat exchanger cool bulk solids having a starting, high temperature to an intermediate temperature before the bulk solids are cooled by the heat transfer plates of the heat exchanger to a resulting, cooled temperature. The cooling of bulk solids to an intermediate temperature by heat transfer tubes described herein before cooling the bulk solids to a resulting, cooled temperature by the heat transfer plate assemblies described herein, increases the operational life of the heat transfer plates and the heat exchanger described herein.

The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole. All changes that come with meaning and range of equivalency of the claims are to be embraced within their scope.

The invention claimed is:

1. A heat exchanger comprising:

a housing including an inlet for receiving bulk solids, and an outlet for discharging the bulk solids;

a plurality of spaced apart, substantially parallel heat transfer tubes disposed within the housing between the inlet and the outlet, for cooling the bulk solids that flow from the inlet, to spaces between heat transfer tubes;

a plurality of spaced apart, substantially parallel high temperature heat transfer plate assemblies disposed within the housing and interposed between the plurality of heat transfer tubes and the outlet for further cooling the bulk solids that flow from the spaces between heat transfer tubes, to spaces between the high temperature heat transfer plate assemblies and to the outlet, ones of the high temperature heat transfer plate assemblies including:

a heat transfer plate comprising a pair of metal sheets coupled together and including spaces between the metal sheets for the flow of cooling fluid between the metal sheets;

a pipe extending along a top of the heat transfer plate to protect the heat transfer plate, the pipe including a fluid inlet at one end thereof for receiving cooling fluid in the pipe;

wherein the high temperature heat transfer plate assemblies are configured to receive cooling fluid into the high temperature heat transfer plate assembly through the fluid inlet of the pipe and for the cooling fluid to flow through the heat transfer plate.

2. The heat exchanger according to claim **1**, wherein first ones of the plurality of heat transfer tubes are arranged in a first row, and second ones of the plurality of heat transfer tubes are arranged in a second row, and wherein the heat transfer tubes of the second row are spaced from the heat transfer tubes of the first row.

3. The heat exchanger according to claim **2**, wherein each heat transfer tube of the second row is disposed between adjacent heat transfer tubes of the first row.

4. The heat exchanger according to claim **2**, wherein third ones of the plurality of heat transfer tubes are arranged in a third row, and wherein the heat transfer tubes of the third row are spaced and aligned with respective heat transfer tubes of the first row.

5. The heat exchanger according to claim **1**, comprising a refractory lining disposed within the housing between a first sidewall of the housing and the heat transfer tubes adjacent the first sidewall of the housing for cooling the bulk solids that flow between the first sidewall of the housing and the first heat transfer tubes located adjacent the first sidewall of the housing.

6. The heat exchanger according to claim **5**, wherein the refractory lining is disposed within the housing between an opposing second sidewall of the housing and the heat transfer tubes located adjacent the second sidewall of the housing for cooling the bulk solids that flow between the second sidewall of the housing and the first heat transfer tubes located adjacent the second sidewall of the housing.

7. The heat exchanger according to claim **2**, wherein the heat transfer tubes extend between a first sidewall of the housing and an opposing second sidewall of the housing.

8. The heat exchanger according to claim **3**, wherein first ends of the heat transfer tubes pass through the first sidewall of the housing and second ends of the heat transfer tubes pass through the second sidewall of the housing.

9. The heat exchanger according to claim **4**, wherein the first ends of the heat transfer tubes of the first row are coupled to the first sidewall of the housing by respective first seals.

10. The heat exchanger according to claim **4**, comprising a cooling fluid inlet manifold in fluid communication with each first seal for providing cooling fluid into each heat transfer tube of the first row.

11. The heat exchanger according to claim **5**, wherein a second end of each heat transfer tube of the first row is in fluid communication with a second end of each heat transfer tube of the second row for providing cooling fluid into each heat transfer tube of the second row.

12. The heat exchanger according to claim **7**, wherein the first end of each heat transfer tube of the second row is coupled to the first sidewall of the housing by a second seal.

13. The heat exchanger according to claim **8**, comprising a cooling fluid discharge manifold in fluid communication with each second seal for receiving cooling fluid discharged from each heat transfer tube assembly of the second row.

14. The heat exchanger according to claim **1**, comprising a plurality of spaced apart, substantially parallel low temperature heat transfer plate assemblies disposed within the housing and interposed between the plurality of heat transfer plate assemblies and the outlet for further cooling the bulk solids that flow from the spaces between the heat transfer plate assemblies, to spaces between the low temperature heat transfer plate assemblies and to the outlet, to a fourth temperature.

15. The exchanger according to claim **1**, wherein the high temperature heat transfer plate assemblies comprise:

a first fluid conduit extending along a first side of the heat transfer plate, the first fluid conduit in fluid communication with the pipe, near a second end of the pipe, to receive the cooling fluid from the pipe, and the first fluid conduit including first openings therein to provide fluid communication between the first fluid conduit and the heat transfer plate for the flow of the cooling fluid into the heat transfer plate; and

a second fluid conduit extending along a second side of the heat transfer plate, which second side is opposite the first side, the second fluid conduit including second openings therein to provide fluid communication between the heat transfer plate and the second fluid conduit for the flow of the cooling fluid into the second fluid conduit, and a fluid outlet for the flow of the cooling fluid out of the second fluid conduit.

16. A heat exchanger comprising:

a housing including an inlet for receiving bulk solids, and an outlet for discharging the bulk solids;

a plurality of spaced apart, substantially parallel heat transfer tubes disposed within the housing between the inlet and the outlet, for cooling the bulk solids that flow from the inlet, to spaces between heat transfer tubes, the heat transfer tubes arranged in rows of tubes;

a plurality of spaced apart, substantially parallel first heat transfer plate assemblies disposed within the housing and interposed between the plurality of heat transfer tubes and the outlet for further cooling the bulk solids that flow from the spaces between heat transfer tubes, to spaces between the first heat transfer plate assemblies and to the outlet, the first heat transfer plate assemblies each including a pipe extending along a top end of a respective heat transfer plate and configured for fluid flow therethrough to protect the heat transfer plate;

a plurality of spaced apart, substantially parallel second heat transfer plate assemblies disposed within the housing, interposed between the first plurality of spaced apart, substantially parallel heat transfer plate assemblies and the outlet for further cooling the bulk solids that flow from the spaces between the first heat transfer plate assemblies, through spaces between the second heat transfer plate assemblies, and to the outlet.

17. The heat exchanger according to claim **16**, wherein the heat transfer tubes are arranged in a first row, a second row, and a third row and wherein heat transfer tubes of the third row are generally vertically aligned with heat transfer tubes of the first row.

18. The heat exchanger according to claim **17**, wherein heat transfer tubes of the second row are generally vertically offset from the heat transfer tubes of the first row.

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